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Storage and Conveyance Alternative Component Refinement Process

Prepared by the CALFED Storage and Conveyance Refinement Team
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I. Introduction

The purpose of the storage and conveyance component refinement process is to develop a range in which the storage and conveyance components are reasonably well balanced in capacities. By this we mean that the selected combination of components would operate efficiently over a normal range of hydrologic conditions, thus incurring the least cost and environmental impact associated with providing water supply opportunities. The results reported here are intended to provide CALFED agencies and stakeholders with an introduction to the use of DWRSIM system simulation modeling, coupled with spreadsheet post-processing, as tools in the component refinement process. It is important to emphasize that the information provided here is very preliminary and subject to revision. Initial component choices in no way reflect an endorsement of or rejection of specific facilities. Increasingly detailed site and facility evaluations will take place as more complete information becomes available and as analytical tools are improved. In addition, a more complete range of operating assumptions and impact analyses will be evaluated in later phases as well.

The Benchmark DWRSIM run (472) was the foundation for the preliminary analysis described in this report. It was based on the assumption that existing facilities and operating constraints would apply, with the exception that export water demands were for the year 2020. Due to the large number of model changes recently incorporated into DWRSIM and the tight scheduling constraints imposed by the CALFED Bay-Delta solution finding process, this run was released before it could be fully evaluated. It will be reviewed and updated as the model changes are fully debugged and verified.

Based on the preliminary Benchmark Run, water supply opportunities and the effects of various storage and conveyance facilities were evaluated using post processing spreadsheets. The spreadsheets were used in place of additional DWRSIM runs due to delays in implementing extensive modifications to DWRSIM (described in the attached assumptions packages) and due to the large number of runs required to define the relationships between the various facilities and water supply opportunities.

This preliminary refinement process evaluated various storage and conveyance components, including north of Delta surface and groundwater storage, through-Delta and dual transfer conveyance, in-Delta storage, and south of Delta surface and groundwater storage. The effect of various combinations of these components, added to the existing water management infrastructure, was also evaluated.

In the spreadsheet post-processing existing facilities could not re-operated to take advantage of new facilities due to the complex nature of the coordinated operations of the CVP and SWP. The process simply identifies available water supply opportunities and allocated that water based on existing operating rules and assumed conveyance and storage constraints. Implemented carefully, this approach can provide reasonable comparative results. Spreadsheet results will be verified by conducting detailed DWRSIM runs, which integrates the operation of the entire system, once DWRSIM modifications are completed. Based on the results of the initial refinement process documented herein, further changes and refinements will be made to achieve balanced combinations of components.

During this refinement process it is impossible to anticipate what changes in operational rules may eventually be selected for operating the system to achieve environmental and water supply objectives. For the most part, it was assumed that the system would be operated according to existing rules, including the May 1995 Water Quality Control Plan. These assumptions are set forth in the attached "**DWR Planning Simulation Model (DWRSIM) Assumptions for CALFED Benchmark Study 1995C6D-CALFED-472**". Additional assumptions were required to operate the proposed additional storage and conveyance components using spreadsheet post-processing. Those assumptions are documented under separate cover. There is substantial uncertainty over future no-project conditions, including implementation of the Central Valley Project Improvement Act, Trinity River flow allocations, allocation of American River flows, coordinated operations of the SWP and the CVP, and third-party participation in the State Water Resources Control Board Water Quality Control Plan implementation. Pending resolution of these and other uncertainties, the Team felt that the most reasonable approach was to proceed by assuming current operating rules. The following paragraphs provide some background regarding the Modeling Team's reasoning in arriving at these assumptions, as well as caveats regarding their intended use.

II. Water Supply Opportunities

The proposed surface and groundwater storage components north of the Delta would be filled only after existing needs for water are met, including in-basin consumptive use, in-stream flow requirements, and Delta protective standards. In addition, this analysis also assumes that further diversions from the Sacramento River system would not occur until adequate seasonal flushing flows had occurred. Such flows are assumed to help restore river gravels, to maintain the river meander zone above Chico Landing, and to move salmon smolts downstream. A preliminary evaluation of the historical record suggests that when Sacramento River flow at the latitude of Hamilton City (River mile 200) equal or exceed 550 thousand acre feet in a given month, the river will experience peak flow in excess 60,000 cfs some time during the month. For the sake of this preliminary analysis, these flows are deemed to be sufficient to meet the need for seasonal flushing.

The post-processing spreadsheet models included the assumption that diversions of water to off stream storage were allowed only after this flushing flow requirement had been met. Flows available for storage are defined as the minimum of:

1) Flows in excess of navigation flows at Wilkins Slough,

2) Flows in excess of minimum salinity repulsion flows at Freeport,

3) Flows in excess of minimum Delta outflow requirements, and

4) Flows that would not cause the Delta Export/Inflow ratio to exceed the acceptable limit.

The same rule was applied to determine when flows could be diverted to north of Delta groundwater storage. When flows were limiting, the spreadsheets gave a higher priority to filling ground water storage reservoirs and second priority to filling surface water storage. The reason for this is that diversion rates to groundwater are often limited by the rates at which water can be injected or infiltrated to storage.

III. Accounting for Water Supply Benefits and Impacts

During the development and review of the storage and conveyance refinement assumptions there was considerable discussion and concern regarding how water supply opportunities could be accounted for. The initial proposal by the Modeling Team was to use changes in SWP supplies as a surrogate for water supply opportunities for all beneficial uses. Several agency representatives expressed concern that this would be too narrow an approach, which could skew the results of the analysis. Accordingly, the spreadsheet analytical approach was modified to include environmental demands and unmet CVP demand as well as unmet SWP demands. It is likely that future storage and conveyance components would be integrated into both the State Water Project and Central Valley Project, with an effect on the water supply from both systems.

To estimate environmental demands, above those defined by existing Delta operating rules and in stream flow requirements, a surrogate was applied which assumed that Delta outflow would not be allowed to fall below 7,000 cfs until reservoir storages were exhausted. This resulted in reservoir filling during times of high flow and releasing it during periods of low flow. This approach does not imply a recommendation that new Delta outflow criteria be set; rather it serves as an example of how such rules can affect reservoir analysis results.

The spreadsheets allowed for varying allocation of available storage to environmental and project purposes, on a pro rata basis.

It was recognized that criteria for sharing resources between the SWP and CVP are uncertain under the May 1995 WQCP, and therefore this issue will need to be carefully reviewed and modified for Phase II of the analysis.

Similarly, there are many ways to allocate new supplies between environmental, agricultural, and urban needs. Various allocation themes can be developed through open CALFED technical discussions and negotiations and bundled as alternative operating constraints. Water supply benefits and impacts can then be compared to specific targets. The relatively crude criteria for protection of in stream values and criteria for release of water for environmental benefits are expected to be refined by the Ecosystem Restoration Workgroup and other CALFED workgroups.

IV. Conveyance Assumptions

The 1994 Bay-Delta Accord is based on the need to protect a wide range of beneficial uses, based on the existing configuration of the Bay-Delta system. A significant alteration of the existing through-Delta water supply system would likely require a re-evaluation both to assure that beneficial uses are protected and to assure that operating rules are not unnecessarily restrictive.

Among the most likely candidates for re-evaluation would be the Delta export-inflow ratios, designed to limit entrainment of eggs, larvae, and fish at in-Delta export facilities. If part of the inflow to the Delta is diverted through one or more screened intakes at the northern end of the Delta into an isolated conveyance channel, that portion of the inflow could be either counted as part of the Delta inflow or subtracted from the Delta inflow. Similarly, export flows taken through an isolated conveyance could be counted either way. Thus without making any changes to the existing Bay-Delta standards there are various ways to compute the export-inflow ratio. The two most likely approaches would be to:

o Include the isolated component in both inflow and export when computing the ratio.

o Delete the isolated flow from both inflow and export when computing the ratio.

The Team felt that the issue of how to account for the isolated export component required discussion among a broad group of stakeholders. To facilitate that discussion and to gain some insight into the sensitivity of the system to changes in this criterion the spreadsheet post-processing was run both ways.

V. Surface Storage Facility Assumptions

In order to evaluate the performance of the various storage components we needed to assume general geographic locations, capacities, and operating rules for filling and emptying. For example, as a surrogate for north of Delta surface storage we assumed a reservoir in the foothills west of Colusa. For south of Delta surface storage, we assumed a reservoir in the vicinity of the existing San Luis Reservoir. In the future, additional analysis will be performed to test the sensitivity of these assumptions for geographic locations.

For in-Delta storage, specific islands were not selected. However, the assumption was made that the islands would be close enough to the SWP and CVP export facilities to provide direct connections through a series of siphons, thus eliminating the need to screen export water from this source twice.

It is important to emphasize that these choices in no way reflect an endorsement of or rejection of specific facilities. Detailed site and facility evaluations will take place in Phase II or Phase III of the process.

VI. Groundwater Storage Facility Assumptions

Groundwater resources can be used to provide increased groundwater storage in several ways. One approach, referred to here as direct groundwater storage, involves treating the groundwater basin like a surface water reservoir, except that it is filled by seepage from percolation basins or injection wells, and emptied by pumping from wells. This approach may involve high capital and operating costs, and is limited by the capacities of project facilities.

A second approach, referred to here as in-lieu groundwater storage, involves varying regional uses of groundwater and surface water resources such that surface water deliveries are supplemented in wet years and cut back in dry and critical years. This results in greater annual variations in groundwater use and storage. The net effect is to make greater stream flows in wet years available for other uses during dry and critical years. The in-lieu approach tends to be more practical and economical, because it takes advantage of water use patterns over large areas and existing water distribution and extraction facilities.

Both of these approaches will be evaluated for the areas upstream of the Delta during the extended component refinement process. However, the extensive DWRSIM programming and input data development required to simulate in-lieu conjunctive use has not been completed at this time. Accordingly, only the groundwater storage option was analyzed.

Direct Groundwater Storage

The evaluation of north of Delta groundwater resources was simplistic due to the lack of detailed hydro-geologic information and lack of operational experience.

The overall approach for modeling direct groundwater storage in the Sacramento Valley was to identify areas in which natural recharge through seepage from nearby streams was relatively slow. During this refinement process it is premature to model specific storage areas; rather it was assumed that the groundwater basins could be simulated as a single basin, with composite recharge, storage, and discharge characteristics. This basin would be incorporated into DWRSIM through a single node, through which flow project recharge, non-project recharge, and pumped withdrawals from storage.

A maximum of 500,000 acre-feet of operable groundwater storage capacity was assumed. A maximum project recharge rate of 500 cfs and discharge rate of 1000 cfs were assumed. In addition, the total non-project recharge capacity was set as a function of the percent of dewatered to reflect hydro geologic constraints.

Non-project recharge was accounted for in project operations whenever the groundwater basins are only partly filled. The rate of recharge is greatest when the groundwater basin is depleted, diminishes as it fills, and ceases at 60 percent of capacity. Whenever artificial recharge occurs, the simulated volume of water in storage is updated, and the natural recharge rate adjusted downward accordingly. These rules simplistically simulated the assumed natural recharge pattern.

Implementation of groundwater storage components which rely on direct withdrawal of groundwater for export from the Sacramento Valley would need to be coordinated with institutional constraints such as Sect 1220 of the Water Code. This Section prohibits groundwater extraction from the Sacramento Valley for export, unless certain conditions are met.

For south of Delta groundwater storage it was assumed that simulating a groundwater storage basin with characteristics like those underlying the Kern River fan would provide insight into the potential effects on water supply opportunities of groundwater facilities developed elsewhere in the San Joaquin Valley. Such facilities have been described in detail elsewhere.

In-Lieu Groundwater Storage

This option involves altering delivery patterns to areas where surface water and ground water resources are both used for irrigated agriculture. In wet years additional surface water would be delivered, allowing groundwater resources to accumulate; in dry and critical years surface water deliveries would be reduced, resulting in a greater use of groundwater storage in meeting total demands.

Various approaches to modeling conjunctive use within DWRSIM have been considered. The most promising approach would involve modifying the input hydrology files for one or more of the Depletion Areas. The demand pattern would have the same shape as the existing pattern within a given Depletion Area; only the annual volume would be adjusted.

The demand during wet years (based on the Sacramento River Index) would be increased to reflect increased surface deliveries, while the demand during dry and critical years would be reduced to reflect increased groundwater use. The current hydrologic record has about 20% wet and 20% dry and critical years.

As a starting point for evaluation, 100 TAF would be exercised in any given year. Subsequent evaluations could look at 200, 300, and greater annual volumes. Due to non-project seepage, additional reservoir releases would be required to transport a given water volume. For example, to deliver 100 TAF, a release of 125 TAF might be required. The 25 TAF would offset non-project recharge.

The net effect of any program which exercises groundwater storage would be a reduction in the long-term average groundwater level (except in areas where groundwater levels are already depressed due to overdraft). Therefore a key criterion for implementation would be that there be no long-term unmitigated effects.

The simulation approach would be similar for both the Sacramento Valley and the San Joaquin Valley.

VIII. Refinement Process Results

The following categories of facilities were considered:

North of Delta (Tributary) Conjunctive Use
North of Delta (Tributary) Surface Storage
In-Delta Surface Storage
Delta Conveyance
South of Delta (Off-Aqueduct) Storage
South of Delta (Off-Aqueduct) Conjunctive Use

Each of the various types of storage facilities noted in this list could be provided with a range of conveyance facilities for moving water to and from storage. In addition, there is a limitless range of possible operating rules for meeting water supply needs and meeting environmental protective goals. As a result, there is a very large number of possible combinations of facilities and operating rules which could be explored to determine which were most effective and economical. For example, if the analysis is restricted to four incremental capacities for each of the above types of facilities, the potential operating rules are bundled into 5 sets, and 5 Delta conveyance configurations are evaluated, there would be over 100,000 possible combinations.

It is not practical to investigate these alternative combinations exhaustively. Instead, the components were first evaluated individually, then evaluated in a few combinations to evaluate their interactions, as follows:

- North of Delta Surface Storage and Conveyance: Determine a reasonable pairing of north of Delta off stream reservoir storage capacity and the conveyance capacity between the reservoir and source stream.

- Individual Storage Components: Evaluate each storage component individually over a range of capacities, assuming existing Delta conveyance capacity.

- Combined Storage Components: Evaluate the effect of one or more storage components working together, assuming existing Delta conveyance capacity.

- Improved Delta Conveyance: Determine the impact of improved Delta conveyance capacity on individual and combinations of north of Delta and off-aqueduct reservoir storage capacity.

North of Delta Surface Storage and Conveyance

A series of spreadsheet analyses were run, varying both reservoir capacity and conveyance capacity to the reservoir. The result was a series of curves as shown on page 42. In general, incremental reservoir water supply contributions decreased with increasing capacity because the odds of filling a reservoir each season decreases. For a given reservoir capacity, incremental benefits of additional pumping capacity also decreased with increasing capacity. Thus there are decreasing marginal rates of return for both storage and conveyance. The upper limits are defined by the available water supply opportunities in the Sacramento River system, by assumed demands for water releases from storage, and by the incremental costs associated with each incremental improvement in water supply.

The relationship between the capacities of the storage and conveyance capacities is a function of relative cost and hydrology. For example, if conveyance capacity is costly relative to storage capacity, the best combination would be a reservoir with relatively small conveyance capacity to and from the river system.

For the preliminary analysis the cost of storage was assumed to follow the cost curve for "West-Side Sacramento Valley Storage (Sites)" and the cost of conveyance was assumed to follow "Conveyance from Chico Landing to the T-C Canal". Costs included both capital and O&M costs, but were based upon simple escalation of previous studies, and are therefore assumed to be low by current standards. Simple cost escalation involves applying a multiplier to the original cost figures to reflect inflation and, to some extent, changes in construction practice. However, such cost escalation may not accurately reflect changing environmental mitigation requirements, new seismic standards, and other cost escalation factors unique to a particular area. The cost curves will be refined as better information becomes available. The selection of these curves does not imply that these facilities have been selected; rather they are used to evaluate and refine the analytical approach, as well as to provide an order of magnitude basis for facilities evaluation.

It was assumed that all water would be provided to the reservoir through the new conveyance from the Sacramento River near Chico Landing, in order to minimize impacts upon the unleveed portion of the Sacramento River most important for salmon spawning and rearing habitat.

The analysis is shown in calculations labeled "(1)North of Delta Storage, Surface, 9/21/96" and "(2)...". Based on these, the following relationships were selected:

Reservoir Capacity	Stream to Reservoir Conveyance Capacity
500 taf	2000 cfs
1000 taf	3000 cfs
2000 taf	4000 cfs
3000 taf	5000 cfs

For any portion of reservoir storage and stream to reservoir conveyance capacity devoted to Delta outflow and north of Delta environmental purposes there is no dependence upon Delta conveyance capacity.

Individual Storage Components

In the spreadsheet post-processing, all new storage reservoirs were assumed to be operated to meet demands without regard to carryover for future years. This had the effect of overestimating reservoir yields since storage is thereby assumed to be more fully exercised each season than would be likely with real facilities. In practice, releases are usually cut back when reservoir storage is depleted as a hedge against drought in following years. In addition, reservoir evaporation was not included as an annual loss in the spreadsheet analyses, again resulting in an overestimate of yield. These factors, coupled with the assumptions that the storages would be used to meet both unmet SWC and CVP demands, result in higher water supply benefit estimates than previously estimated. The results are very preliminary, and are presented in order to familiarize CALFED participants with the analytical tools and general patterns of system response to new facilities.

A range of north of Delta surface storage capacities from zero to 8,000 thousand acre-feet was evaluated. The average annual incremental gains in water supply opportunities were plotted as a function of storage capacity. The average annual water supply opportunities were evaluated for the entire 71 years of record as well as for the critical 7 year period from March, 1928 to February, 1935.The evaluation was performed three different ways: Assuming that all the water would be devoted to project water supply, that all the water would be devoted to environmental enhancement, and assuming that the water would be devoted to both, in a 50/50 split. Figures 1, 2, and 3 show the results.

When the reservoir is devoted exclusively to either environmental or project purposes, the annual water supply benefit curves are similar. For benefits averaged over the entire period of record, there is a clear decrease in slope at about 600 TAF-800 TAF capacity, with smoothly decreasing benefits thereafter. Although the maximum size would ultimately be affected by cost, it is clear that beyond 2,500 TAF the incremental gains in benefits are slight. For benefits averaged over the critical period, the two break points are at 400 TAF and 2500 TAF respectively.

When the reservoir capacity is allocated 50/50 between environmental and project uses, the benefits curve for benefits averaged over the entire 71 year period of record rises correspondingly, indicating that demand, rather than available water supply opportunities, limited the benefits of the reservoir when devoted to a single purpose. As Figure 3 shows, for benefits averaged over the entire 71 year period of record, there is a break point at 1000 TAF, with gradually decreasing slope thereafter. For benefits averaged over the critical period, the two break points are at 400 TAF and 2000 TAF respectively and the net benefits curve is lower than for the single purpose options, because the heavy demands on the reservoir during periods of inadequate supply drain the reservoir sooner.

North of Delta groundwater storage was limited to a maximum of 500 TAF maximum depletion, as described earlier, but evaluated over a range of 0-700 TAF. With flow to storage limited to 500 cfs and pumping from storage limited to 1000 cfs, there is one break point in the curve at 100 TAF and none thereafter (Figure 4). This reflects the fact that the assumed groundwater storage configuration is not nearly large enough nor with sufficient in/out capacity to take advantage of available water supply opportunities.

In-Delta Storage was evaluated over a range of 0-700 TAF (Figure 5). In-Delta storage was operated for both environmental and project benefits. There is no distinct break point in the supply benefits curve, which decreases in slope monotonically throughout. The maximum storage capacity as a stand-alone project would be dictated by economics and physical constraints.

South of Delta surface storage was evaluated over a range of capacities between 0 and 3,000 TAF (Figure 6). For both the 71 year period of record and the 7 year critical period, there is a distinct break point in the vicinity of 400 TAF to 500 TAF with existing conveyance capacity.

South of Delta groundwater storage was evaluated over a range of capacities between 0 and 500 TAF (Figure 7). For both the 71 year period of record and the 7 year critical period, there is a distinct break point in the vicinity of 100 TAF with existing conveyance capacity.

Combined Storage Components

North of Delta surface storage and north of Delta ground water storage were analyzed in combination (Figures 1 and 8). For supply benefits averaged over the 71 year period of record, the addition of groundwater storage causes the surface reservoir benefits curve to flatten out at a lower storage threshold, 400 TAF - 600 TAF, rather than 600 TAF - 800 TAF for the surface storage reservoir alone. For the critical 7 year period, the supply benefits curve levels off at a somewhat greater storage, closer to 3,000 TAF rather than 2,500 TAF, and the average annual supply is greater. This reflects the fact that the groundwater storage provides a portion of the critical period supply, delaying the time at which the surface reservoir is drained.

It is most likely that new surface storage north of the Delta would be developed together with implementation of conjunctive use of groundwater. At this early stage of evaluation, with the given operational assumptions, it is reasonable to set the upper limit on north of Delta surface storage at 3,000 TAF.

In-Delta storage was analyzed in combination with north of Delta surface storage and groundwater storage on the assumption that the facilities would be competing for the same supply. Figure 5 shows in-Delta storage alone, whereas Figure 9 shows it in combination with full development of north of Delta surface and groundwater storage (3,000 TAF and 500 TAF respectively). There was virtually no change in the net storage benefits of the in-Delta storage facility, indicating that it can take advantage of additional water supply opportunities further downstream in the river system. Therefore the in-Delta storage facility should not be initially limited to less than 400 TAF. Further economic evaluation of this option would set the upper limit on viable storage capacity, given the gradual decline in incremental benefits with increasing capacity.

South of Delta surface storage and south of Delta ground water storage were analyzed in combination (Figures 10 and 11). For supply benefits averaged over the 71 year period of record, the addition of groundwater storage causes the groundwater reservoir benefits curve to decline with increasing surface. For the critical 7 year period, the groundwater benefits curve declines more rapidly, indicating that water supply is insufficient to charge both surface and groundwater storages prior to the critical period. The results are to some extent an artifact of the analytical process. All storage components are assumed to be empty at the beginning of the spreadsheet analysis in order to eliminate the effect of various combinations of components on starting system storage. It is probably unrealistic to begin by assuming that groundwater storage is fully depleted at the beginning of the simulation. Second, the distribution of water between the south of Delta groundwater and surface water storage components is arbitrary in the spreadsheet post-processing: It assumes that groundwater storage is filled after surface storage. Nevertheless, it is reasonable to conclude that the as the combined groundwater and surface storage volume is increased substantially beyond 1,000 TAF, there are sharply reduced benefits, due to the inability of the system to supply enough water for storage.

It is most likely that new surface storage south of the Delta would be developed together with implementation of conjunctive use of groundwater. At this early stage of evaluation, with the given operational assumptions, it is reasonable to set the upper limit on south of Delta (off aqueduct) combined storage capacity at 1,000 TAF or less, assuming current Delta conveyance constraints.

Improved Delta Conveyance

The storage and conveyance refinement process will ultimately examine the relative benefits and impacts of various Delta conveyance options on water supplies, water quality, aquatic resources, and numerous other resource categories. In this preliminary analysis it was assumed that the existing Delta operating rules would be in effect. These offer no significant advantage to isolated conveyance alternatives as compared to through-Delta alternatives in terms of water supply opportunities. As described under IV. Conveyance Assumptions, the effect of exempting the isolated component of Delta export flows from the inflow-export ratio was evaluated and found to be relatively insignificant. Accordingly, in this analysis we cannot distinguish between various Delta conveyance improvement options, but merely simulate their common assumed effect: Export capacity would be limited only by the physical capacity of the SWP and CVP pumping plants and available water supplies above those required to meet existing and proposed Delta operating rules.

The storage components most likely to be affected by improved Delta conveyance would be south of Delta storage. Figure 10, in comparison with Figure 6, shows the significantly improved benefits of south of Delta storage in conjunction with improved Delta conveyance. The supply benefits curves for both the 71-year average and the 7-year critical period average reach about twice the benefits and break points in slope are at greater storage thresholds. Inspection of Figure 10 suggests that a storage volume of up to 1,500 TAF provides benefits during the critical period. Even larger storage volumes provide benefits when averaged over the 71-year period. !,500 TAF or more storage capacity
should be considered in further analyses for which Delta conveyance improvements are assumed to be completed.

When south of Delta groundwater storage is added (Figure 11), the supply benefits of south of Delta groundwater storage are somewhat diminished as surface storage capacity is increased, indicating that these facilities would to some extent compete for available storable water and in meeting south of Delta demands. That there is no discernible effect on the south of Delta surface storage benefits curves is an artifact of the spreadsheet post-processing; the surface reservoir is given priority in competing for available supplies.

When north of Delta surface and groundwater storage are added to the system, this has the effect of depressing the supply benefits curve for south of Delta surface storage. Thus the effect of a system wide diminishing rate of return was noted (Figures 12, 13, and 14). Figure 14 compares the incremental gain in supply benefits for incremental gain in storage capacity (slope of the supply benefits curves). It shows that a given incremental gain is reached at a significantly lower south of delta surface storage capacity when the other storages are available. For example, the gradient of 0.4 TAF per year of supply per TAF of added storage capacity is reached at 670 TAF for the south of Delta storage facility acting alone, but is reached at 360 TAF when combined with the other storages. Adding in-Delta storage would further accentuate this effect.

This result would suggest that optimal south of Delta surface storage would be significantly less when combined with other storages, and would probably be in the range of 1,000 to 1,500 TAF, depending upon operational rules and economic analyses.

A more detailed analysis would also include the marginal value of water during times of scarcity. During a drought, as water use is increasingly directed to high value uses such as keeping orchards alive, maintaining key industries, direct human use, emergency services, and so on, the marginal value of water may rise to $2000 per acre-foot. Therefore, even though the marginal improvement in annual water supply improvement might be relatively small as reservoir storage becomes large, the value of that additional supply during drought might make it worthwhile. It will therefore be necessary to conduct such a detailed economic evaluation to accurately identify the appropriate reservoir volume.

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Figure 1. Single Component Sensitivity, WP=1, North of Delta Storage

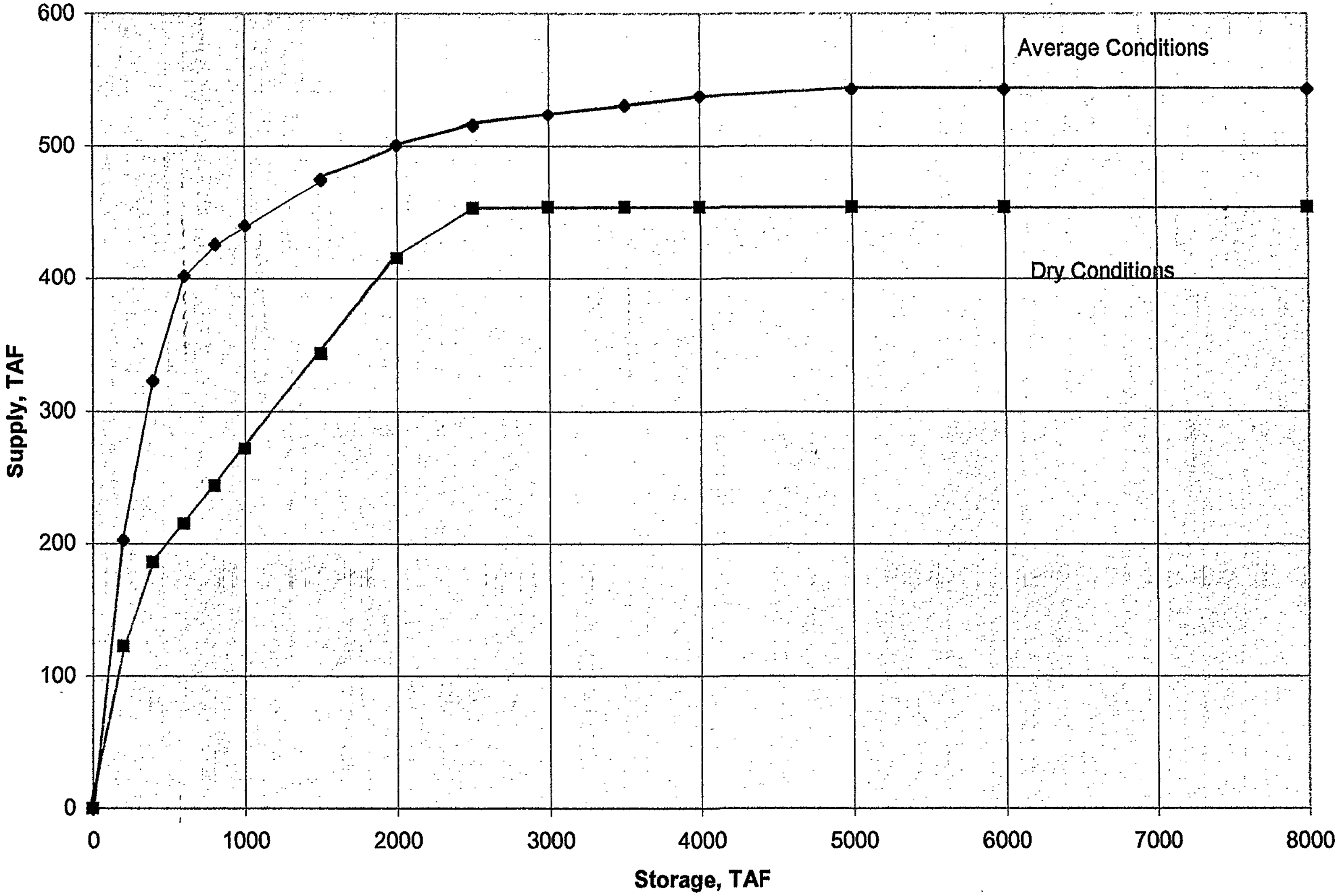

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Figure 2. **Single Component Sensitivity, ENV=1, North of Delta Storage**

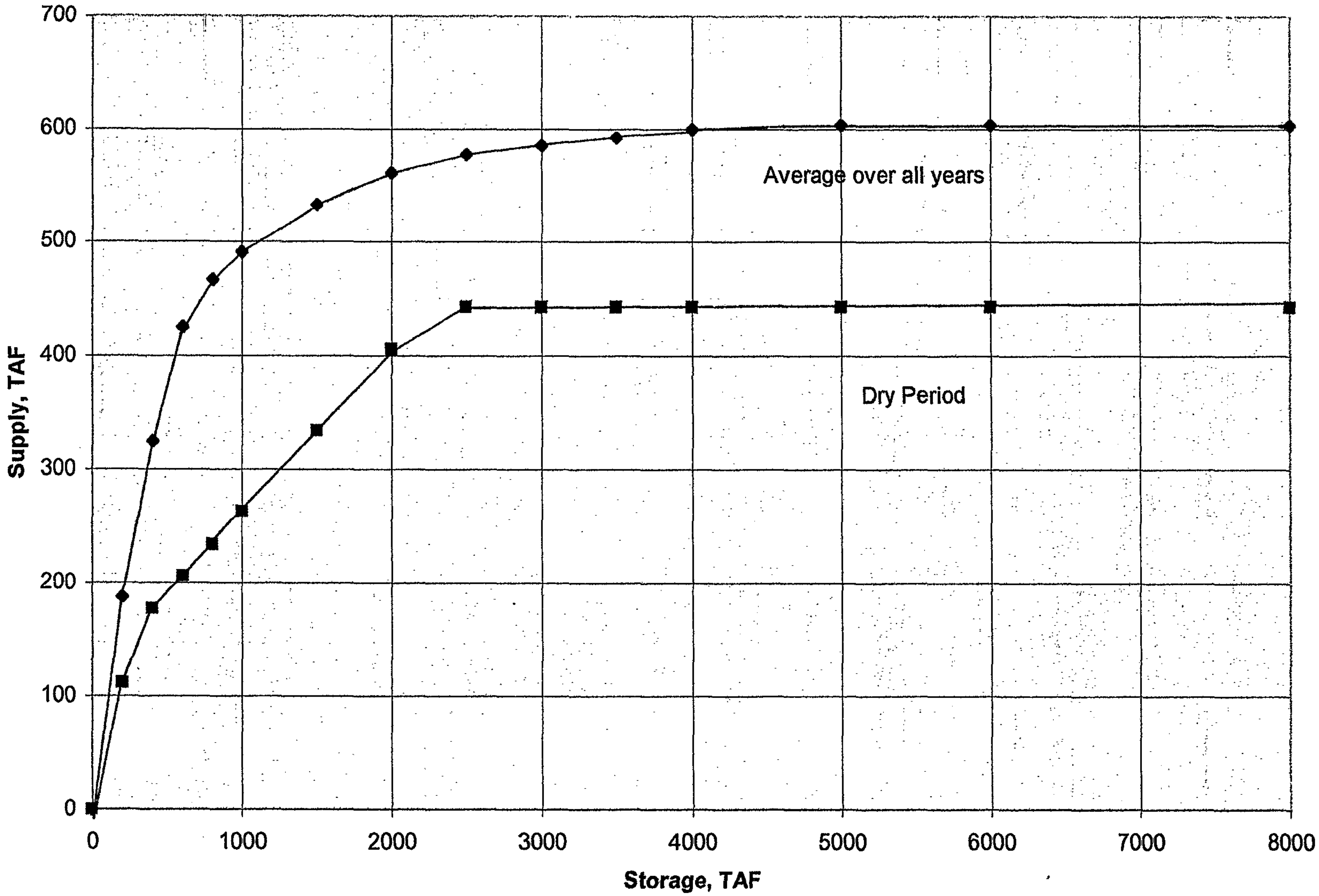

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Figure 3. **Single Component Sensitivity, WP=0.5,ENV=0.5, North of Delta Surface Storage**

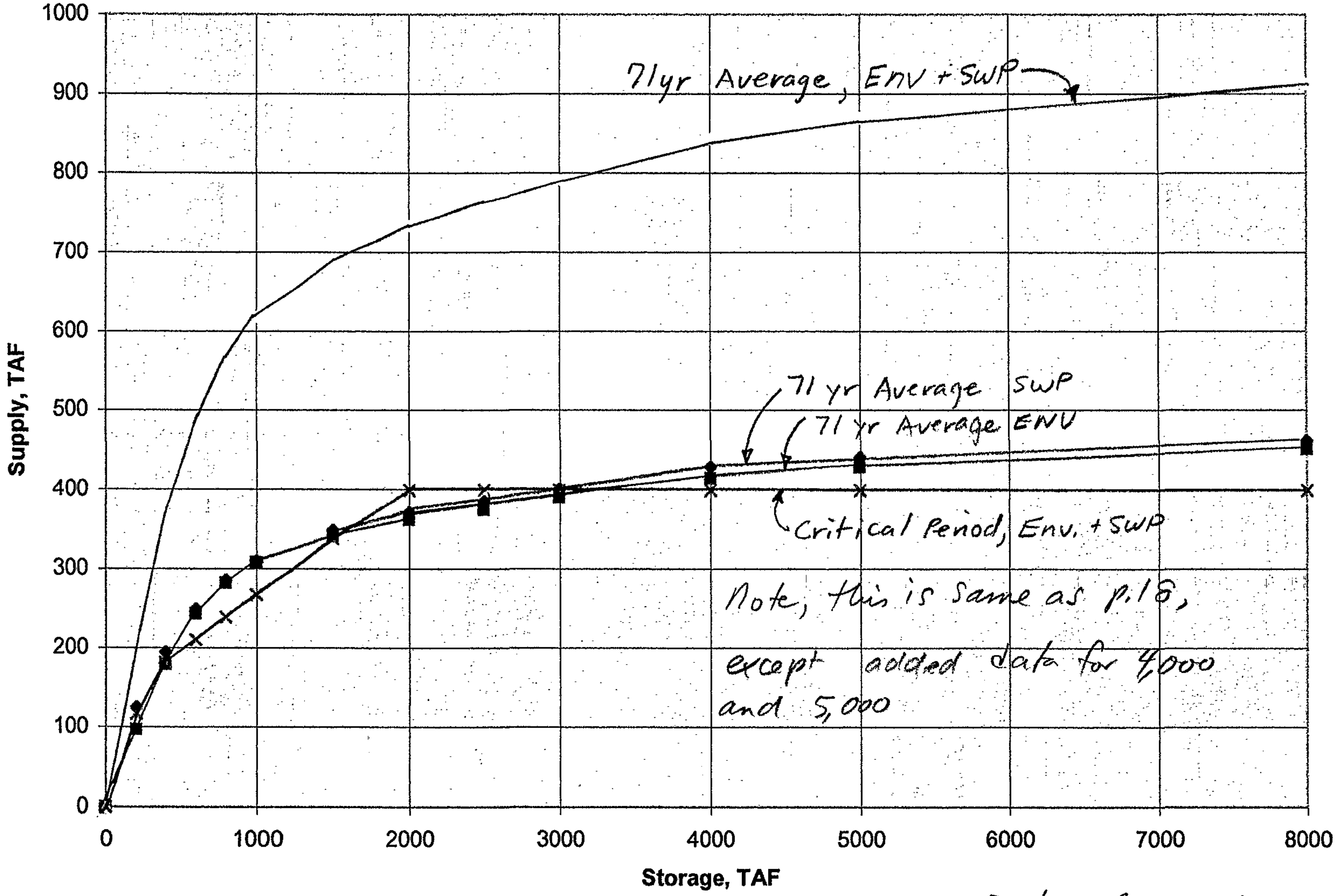

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Figure 4. Single Component Sensitivity, WP=1, North of Delta Groundwater Storage

ENV=1 same

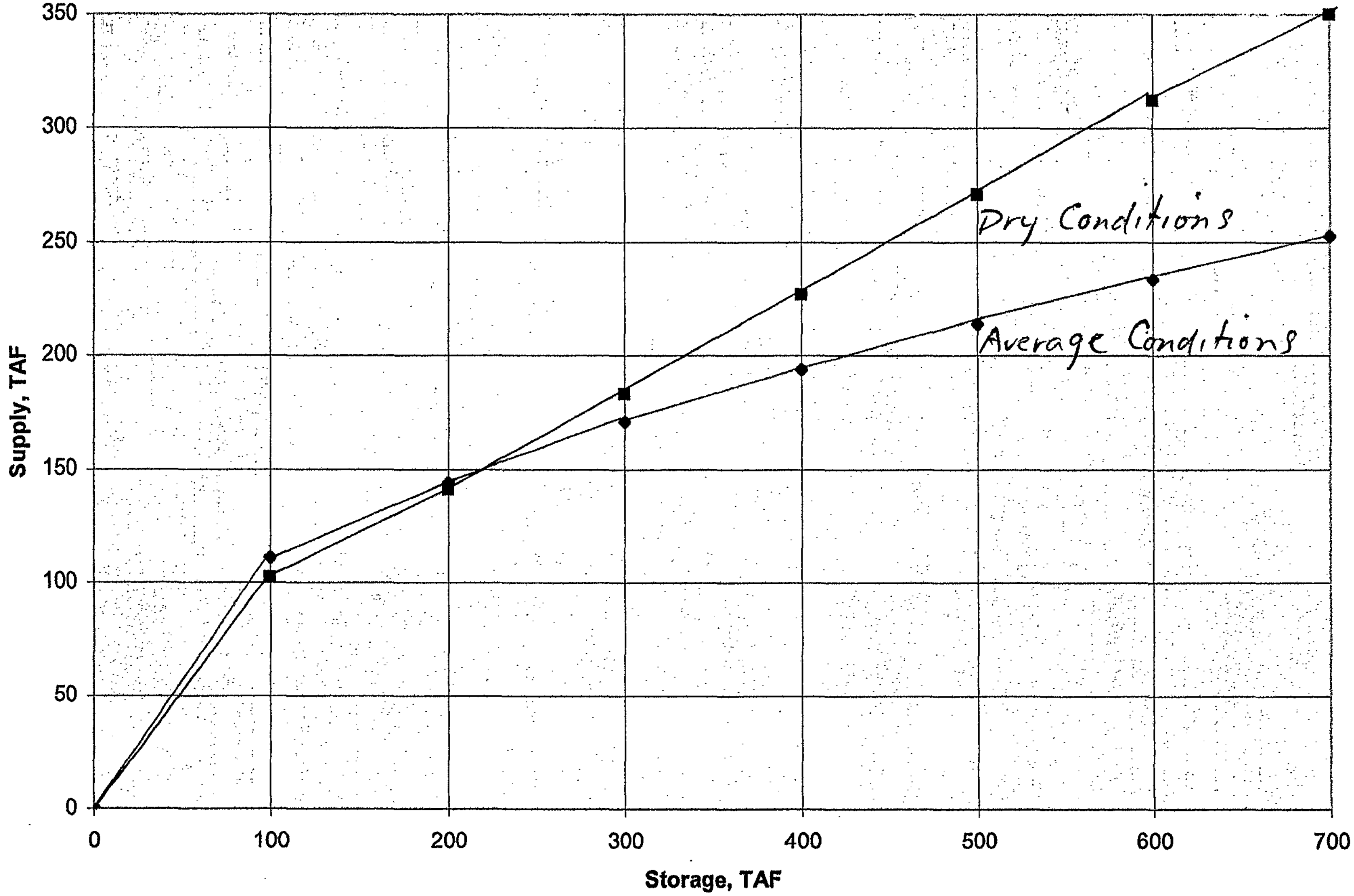

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Figure 5. Single Component Sensitivity, Variable Split, In-Delta Storage

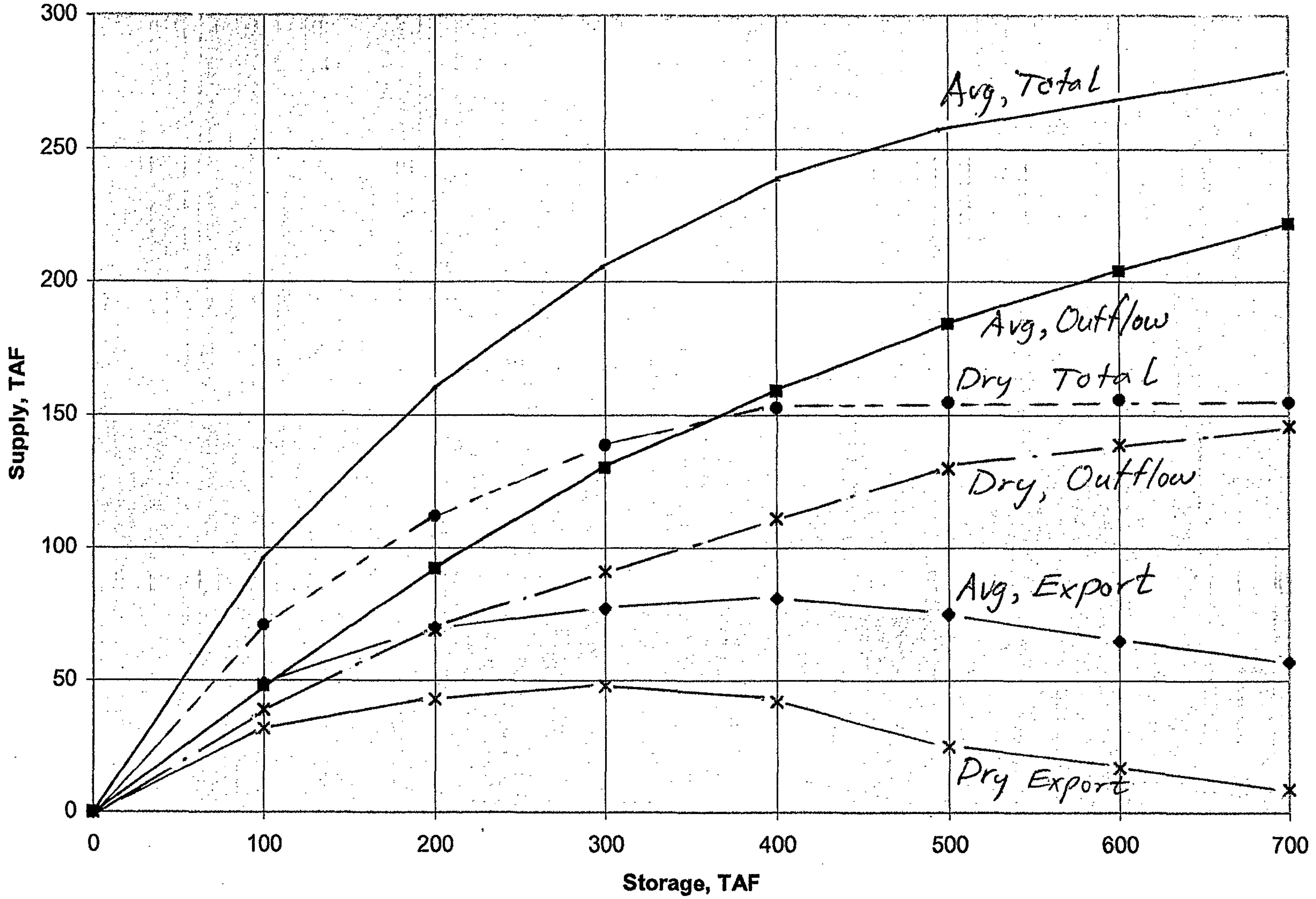

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Figure 6. Single Component Sensitivity, WP=1, South of Delta Storage

ENV=1 Same

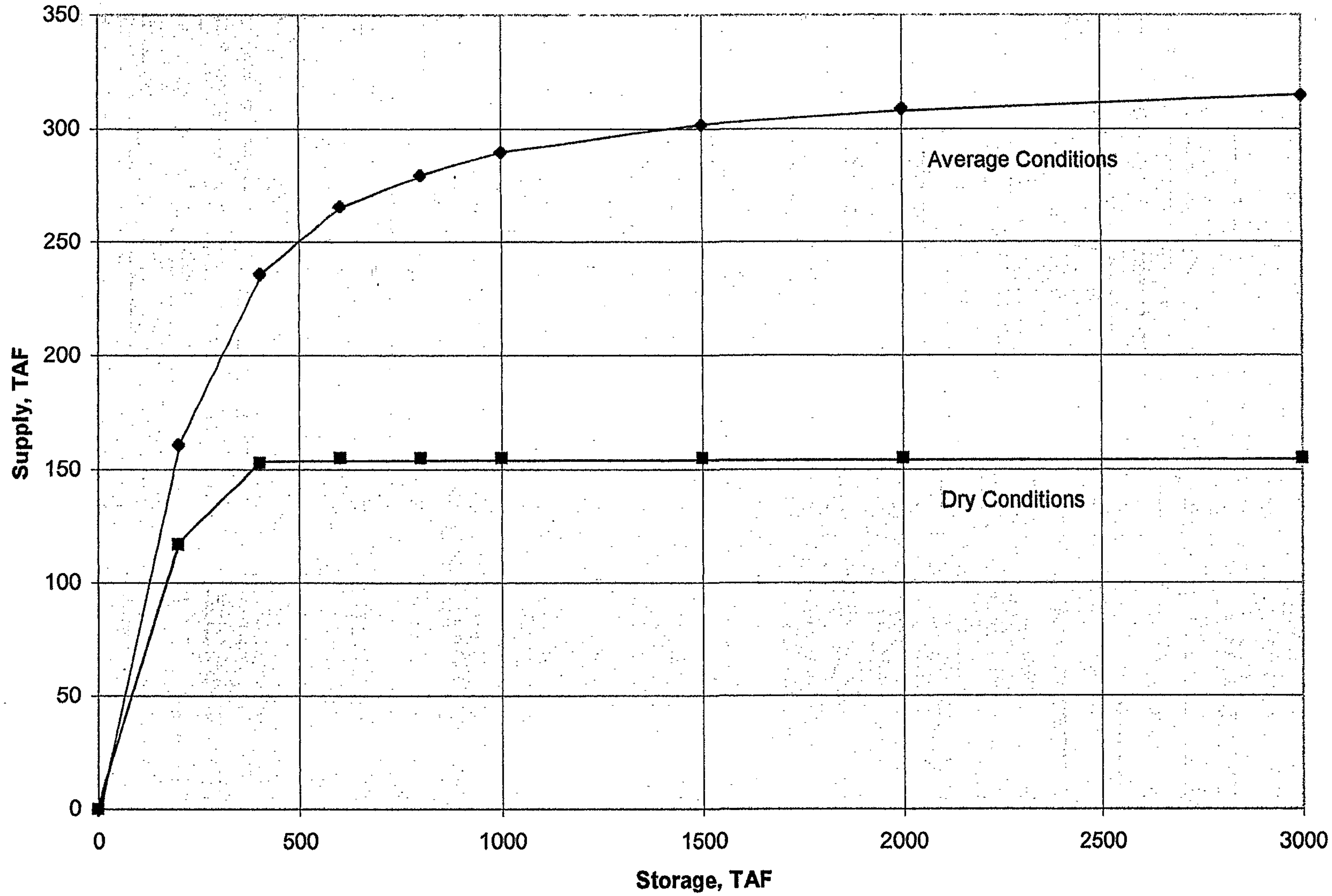

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Figure 7. **Single component sensitivity, WP=1, South of Delta Groundwater Storage**

ENV=1 , same

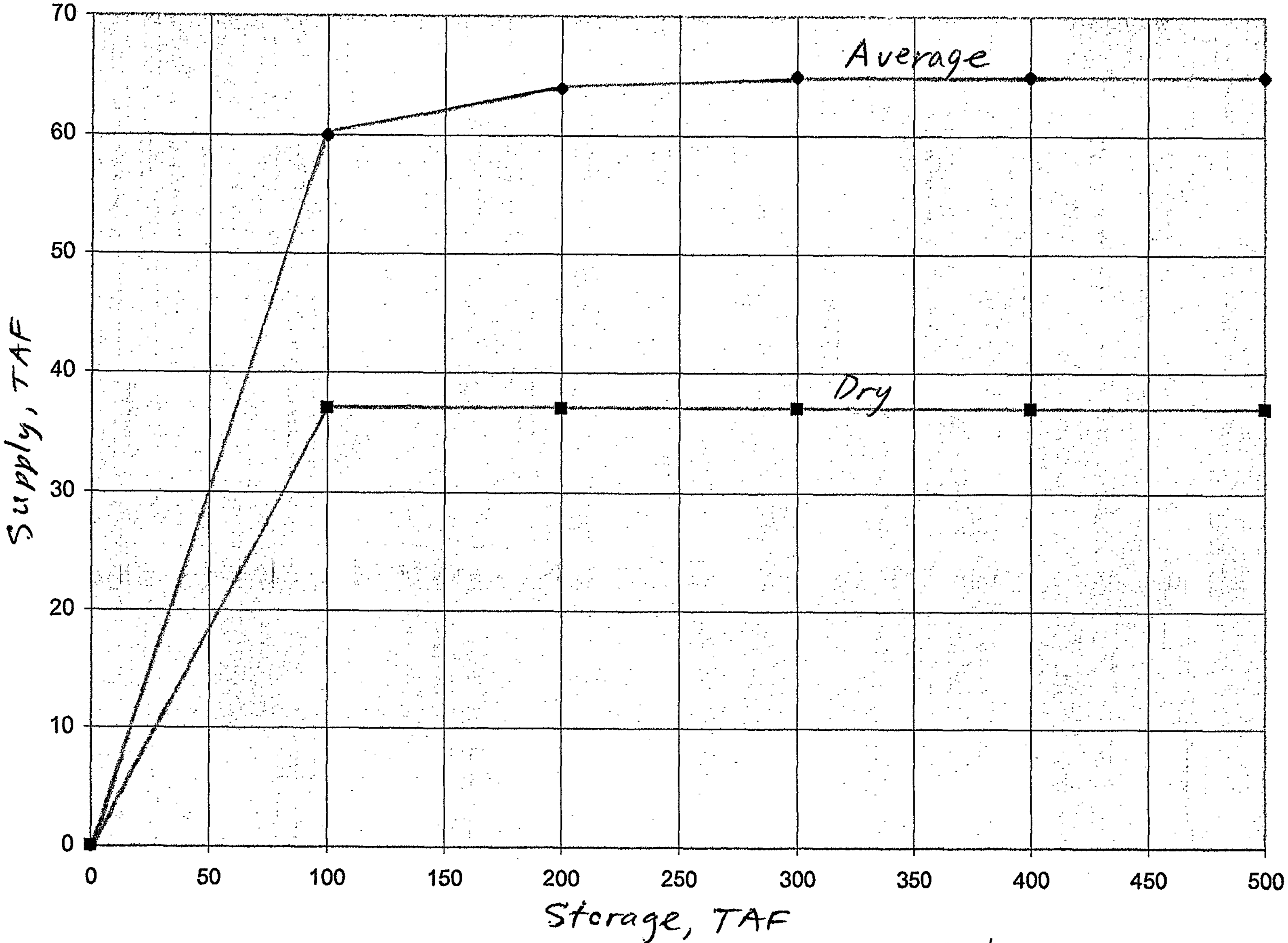

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Figure 8. Dual Component Sensitivity, WP=1, North of Delta Surface Storage + 500 taf gw

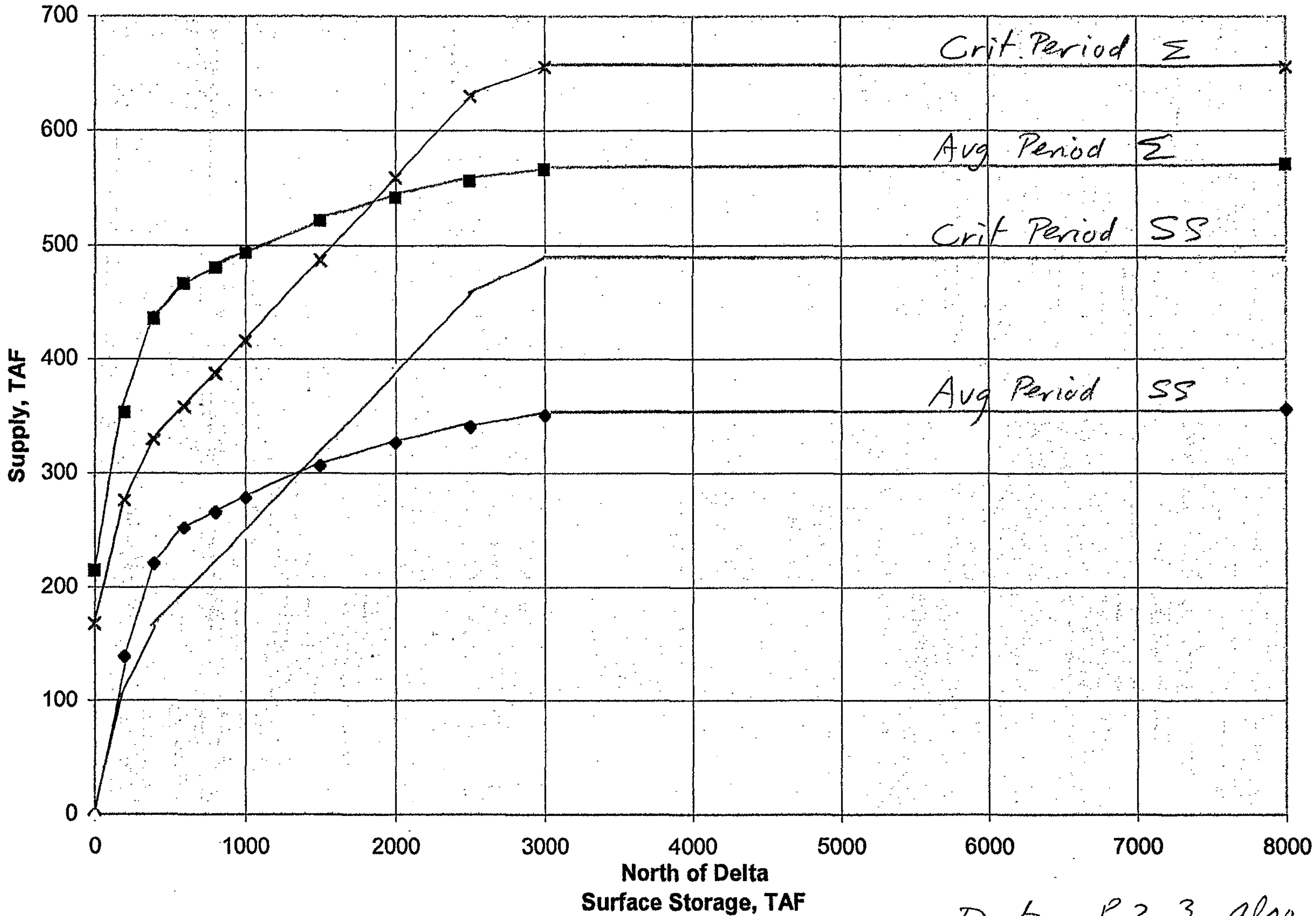

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Figure 9. Dual Component Sensitivity, In-Delta with Max North of Delta Surface and GW Storage

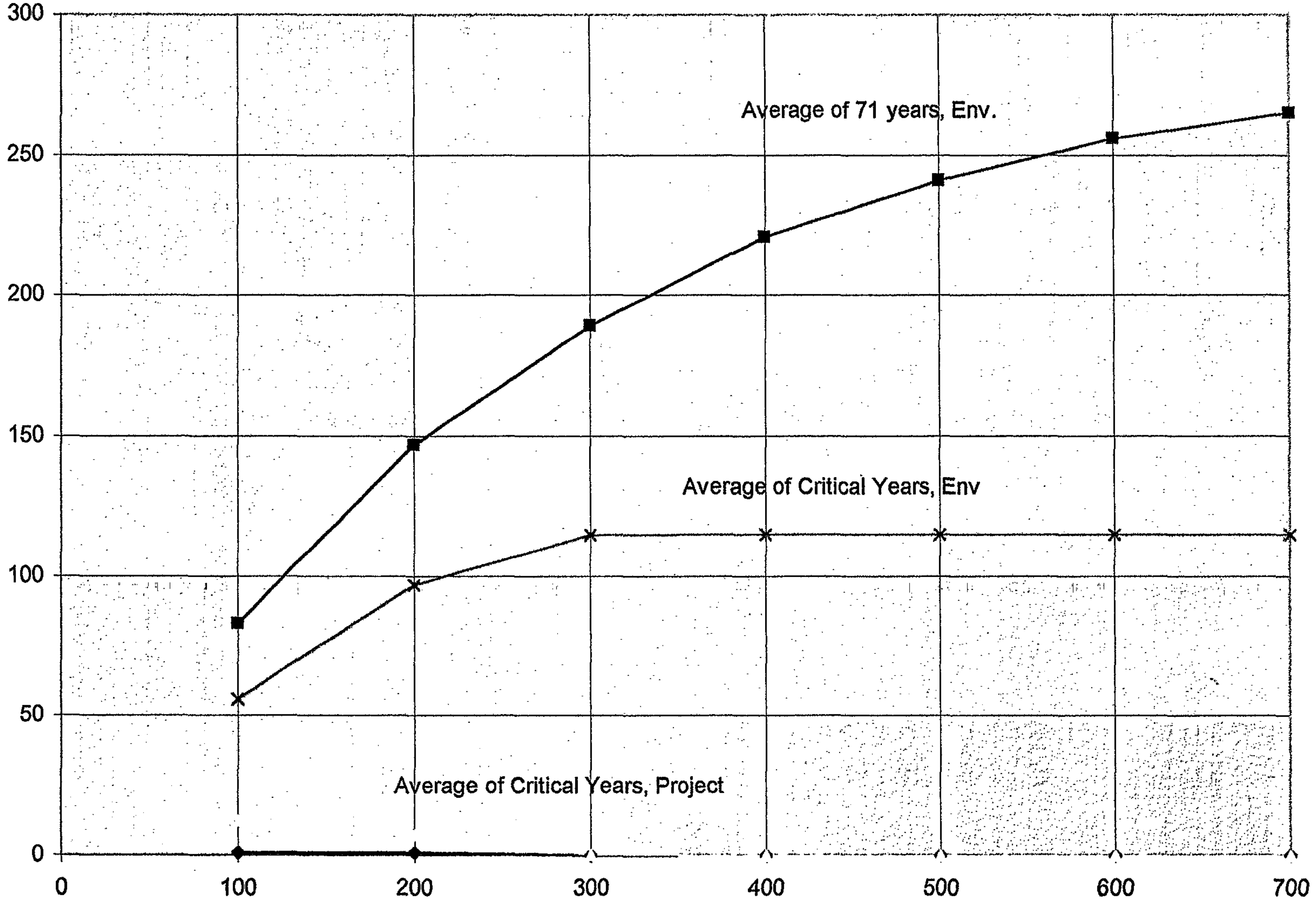

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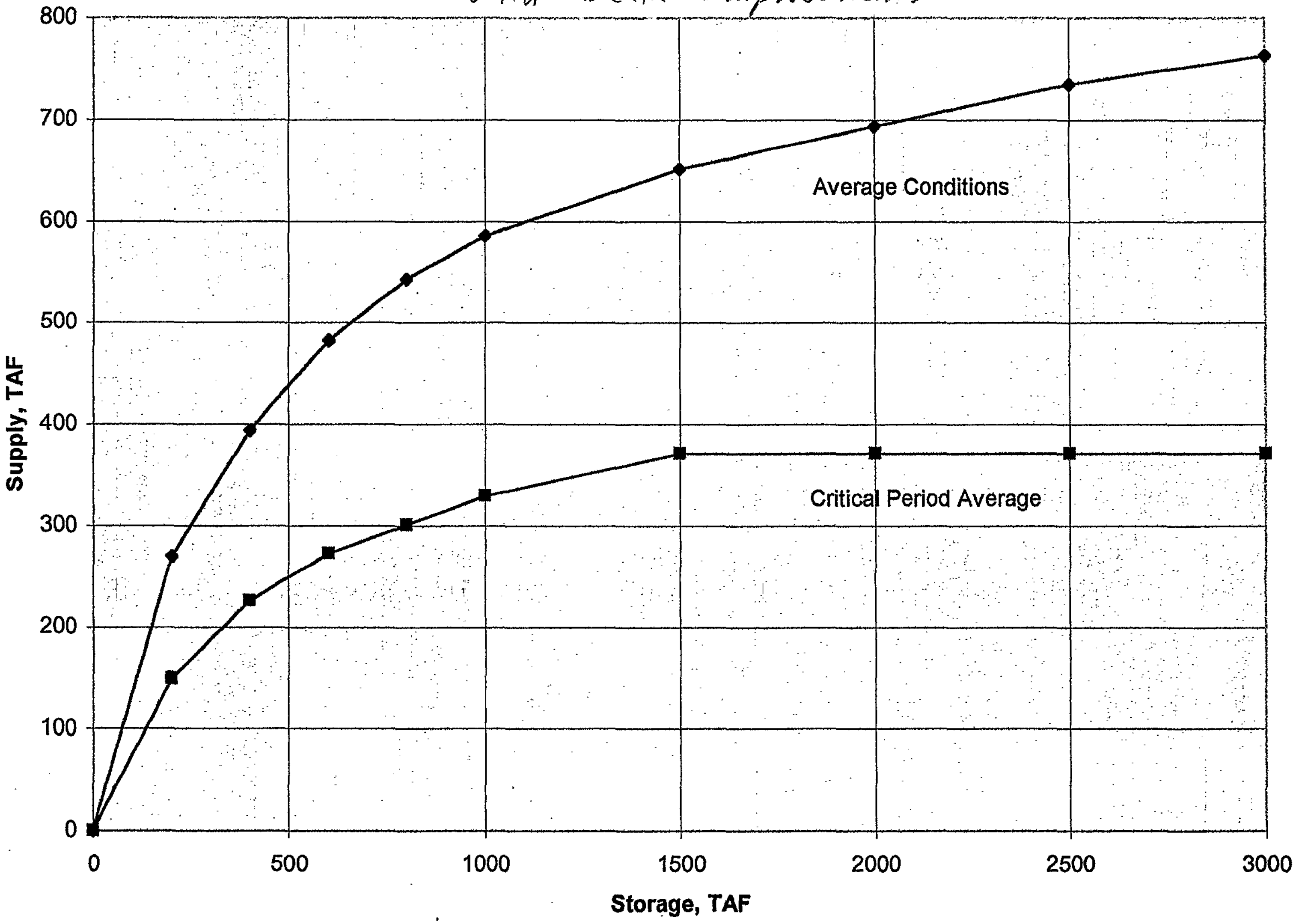
Figure 10. Single Component Sensitivity, WP=1, South of Delta Storage

with Delta Improvements



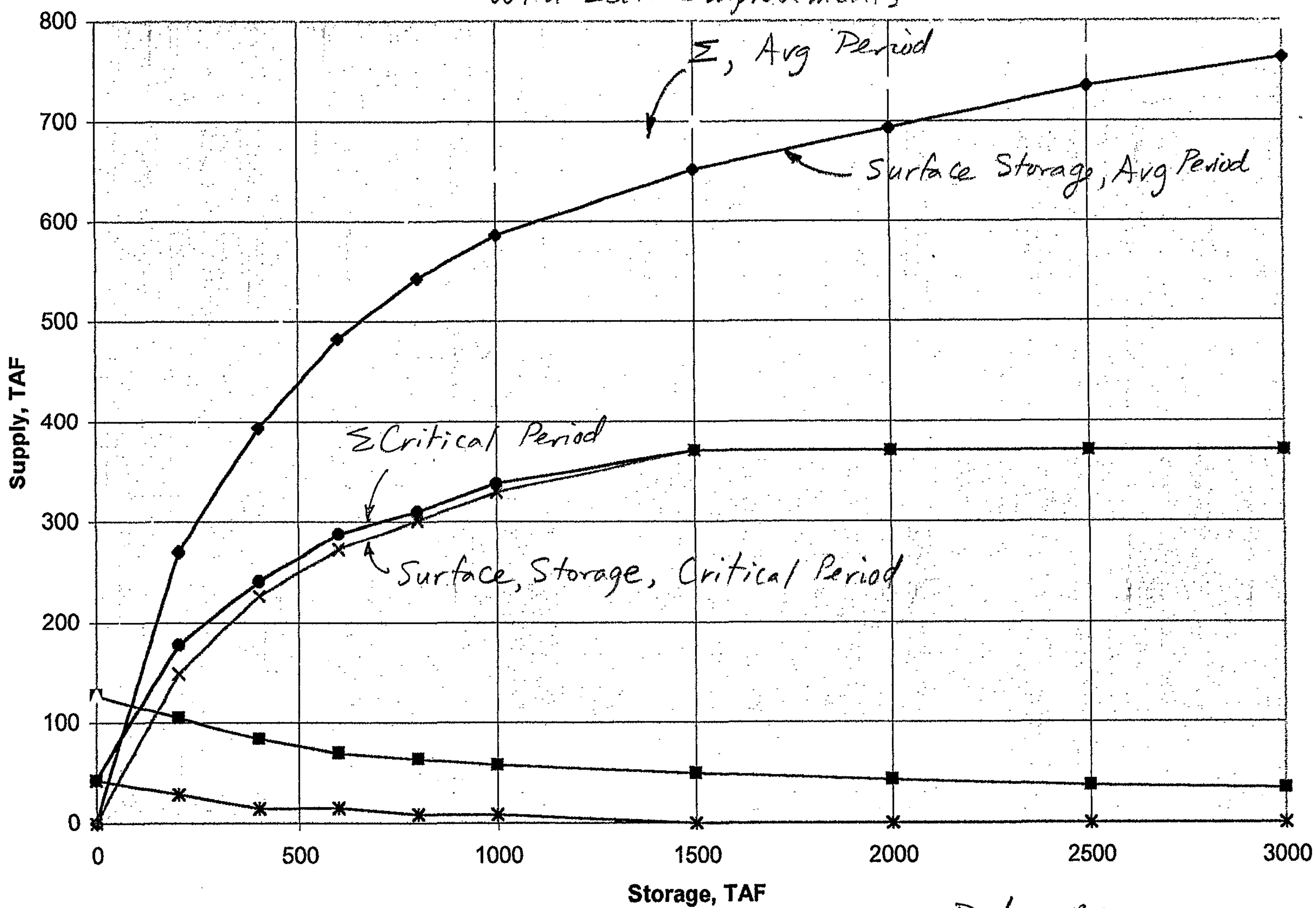
Data P. 25, 26

22

20

Figure 11. Dual Component Sensitivity, South of Delta Storage +GW

With Delta Improvements



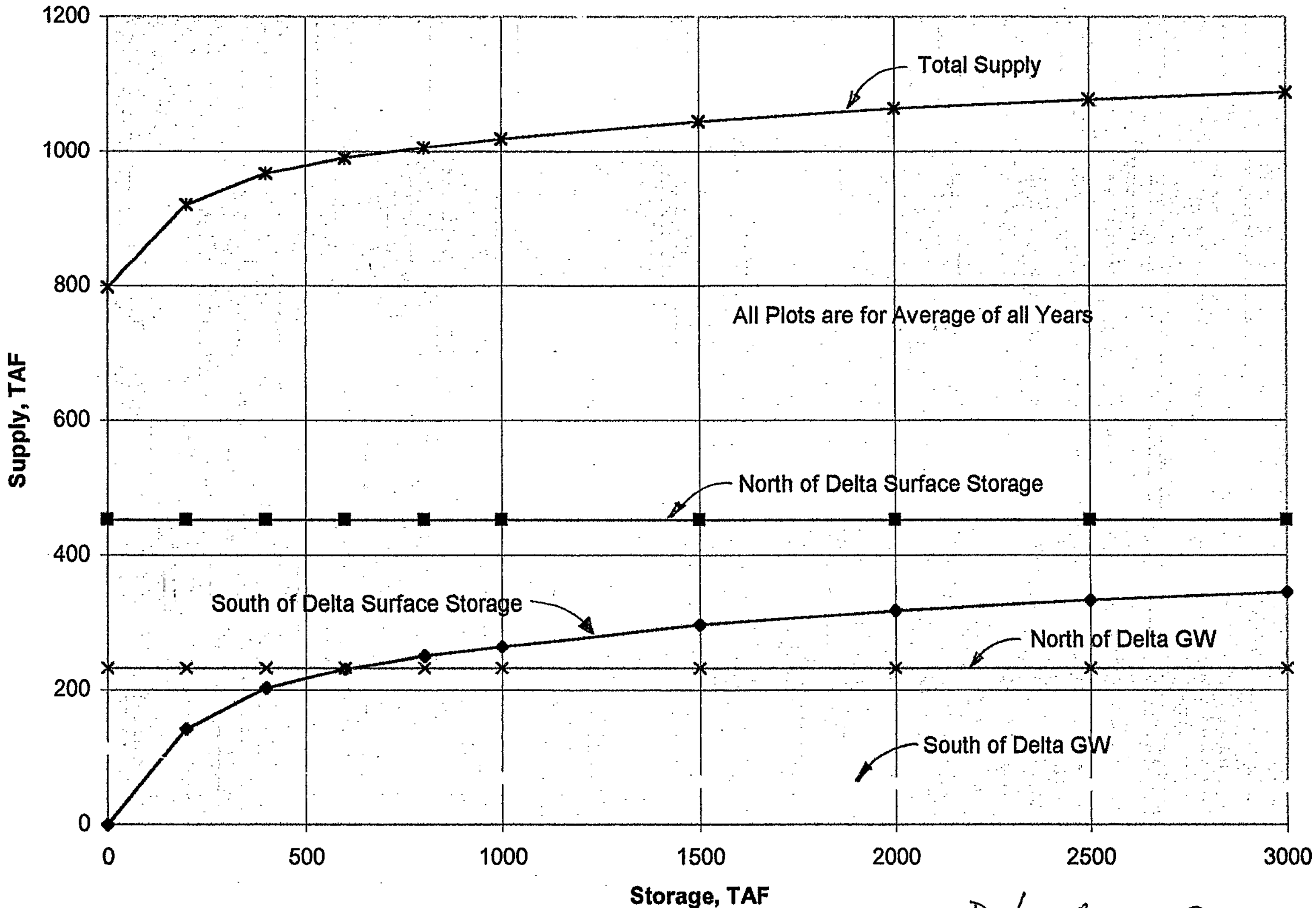
Data P. 27, 28

12

23

Figure 12. Effect of North of Delta Storages on South of Delta Storage

SmB 9/29/96



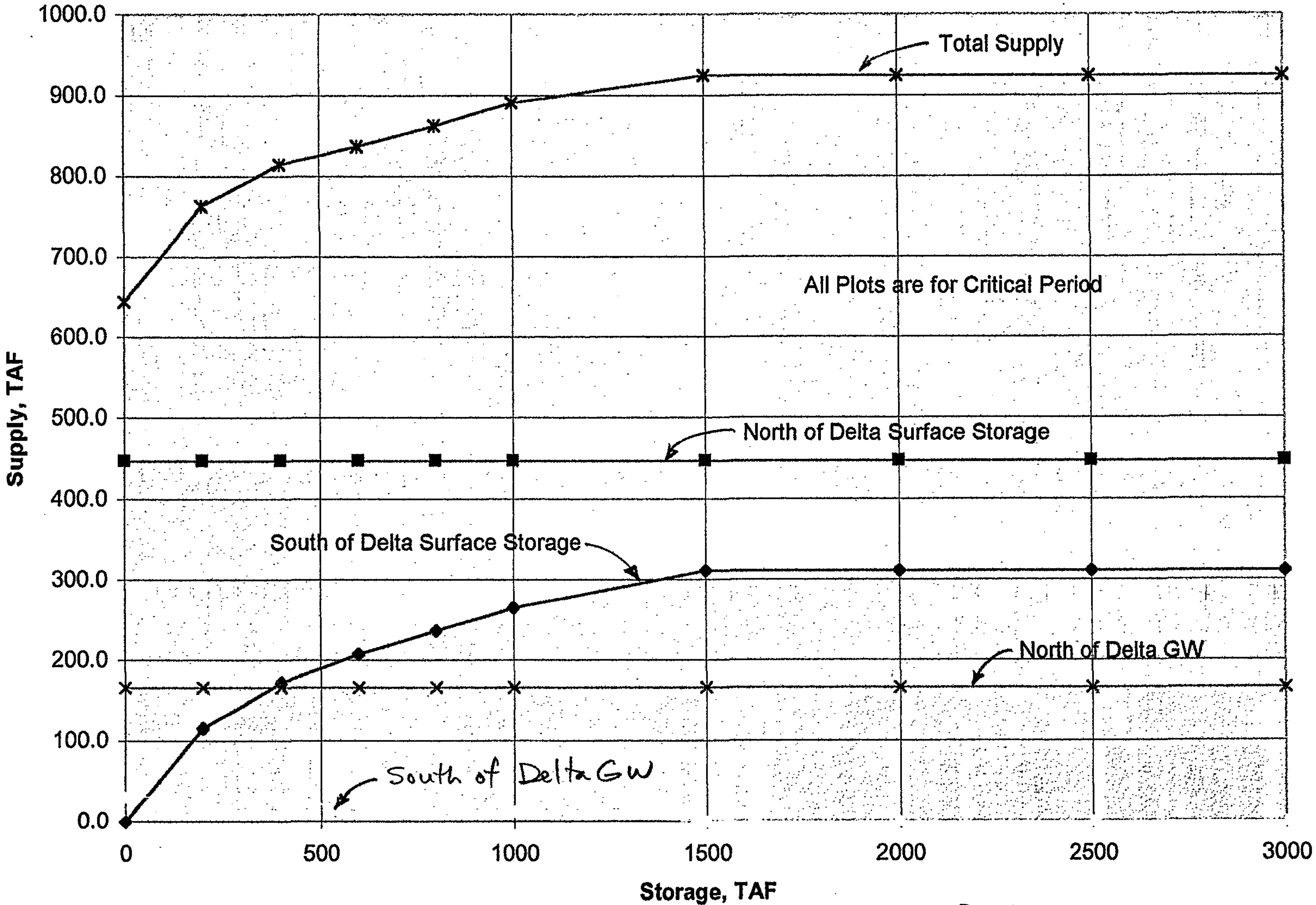
Data P. 27, 28

24

22

Smr 9/29/96

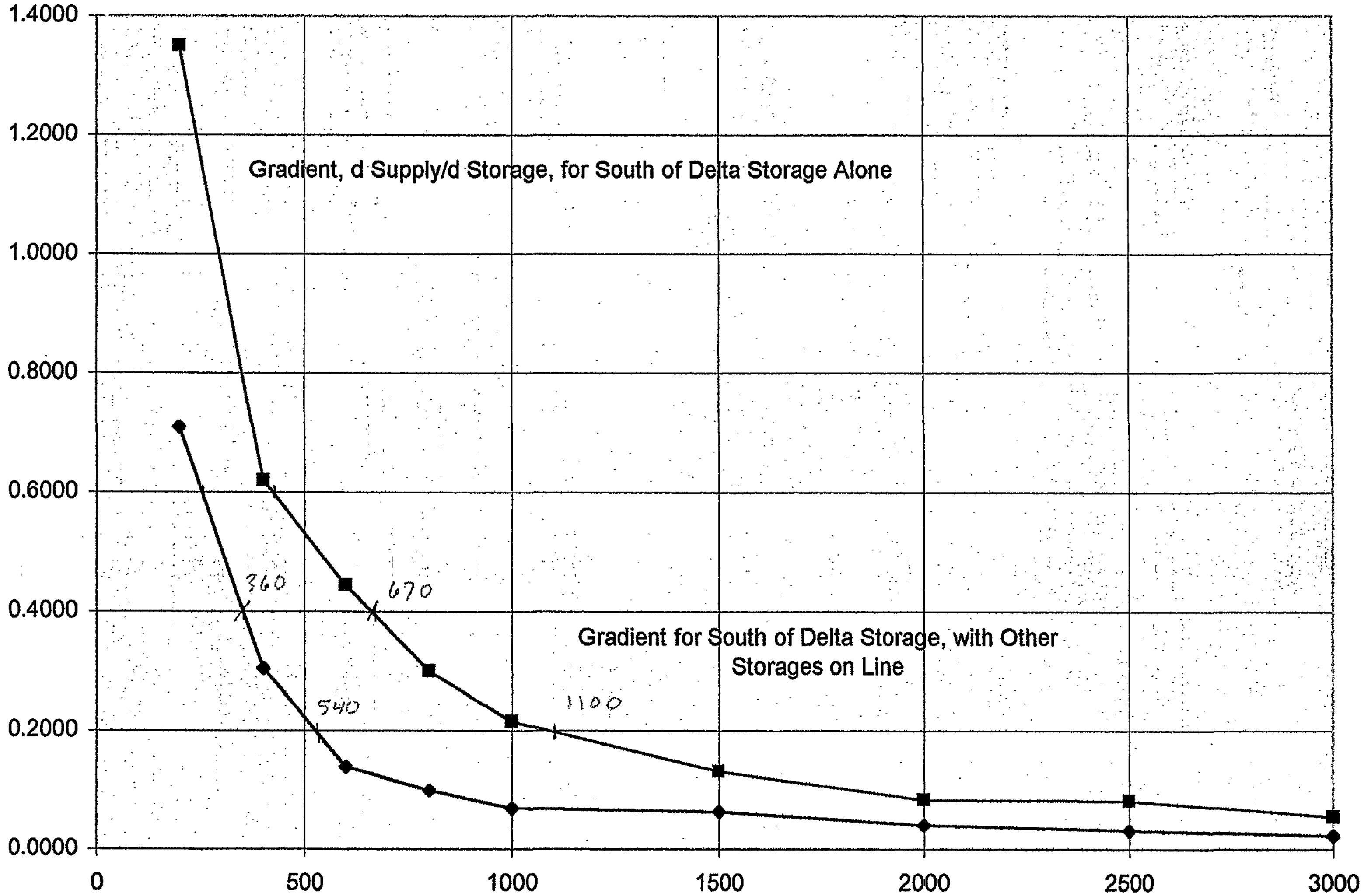
Figure 13. Effect of North of Delta Storages on South of Delta Storage



Data p. 27, 28

E-009537

Figure 14.
Comparison of Supply/Storage Gradient for South of Delta Surface Storage, with and without Other Storages



Data P. 26, 28, right margin

26

24

E-009537